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Significance Of P-Delta Effects In High Rise RC Structure In Various Seismic Zones

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Abstract: Indian codes deal with Linear static (Equivalent static method) and linear dynamic (Response Spectrum method) methods of analysis. Guidelines are also given for Non-Linear dynamic analysis (Time history analysis) for the lateral load analysis. IS codes are silent about the guidelines for geometric non-linearity in the structure. In the case of low or medium rise structures, the geometric non-linearity will not have a significant effect, but for high rise structures, geometric non-linearity becomes a major issue. In this paper a G+50 storey RC structure with vertical irregularity is considered in such a way that P-delta effect is significant and the structure is analyzed by Linear Dynamic analysis as per IS codes and P-delta effects are included and analyzed as per ASCE code. The results such as displacement, storey drift, storey shear are compared and the significance of P Delta effects in high rise structure is studied.

Keywords: P Delta analysis, Non-linearity, Stability coefficient, Vertical irregularity.

1. Introduction

As India a developing country, it requires increase of infrastructure facilities along with the growth of population. Due to increased population, the demand and cost of land for housing is increasing day by day. To fulfill the need of the land for housing and other commercial purposes, vertical development is (high rise multi-storey buildings) the only option. This type of development needs safety because these multi-storey buildings are highly susceptible to additional lateral loads due to earthquake and wind. In other countries, as the elevation of building increases, its reaction to lateral load also increases. Multi-storey reinforced concrete buildings are vulnerable to excessive deformation, which necessitate the introduction of special measures to decrease this deformation. The architectural requirements are increasing now days leading to different kinds of structural requirements which in turn leads to many irregularities in the structure. It is very difficult to analyze those structures with those irregularities. However Indian codes provide guidelines to handle these irregularities to a certain extent.

Vertical geometric irregularity shall be considered to exist, when the horizontal dimension of the lateral force resisting system in any storey is more than 125 percent of the storey below. In buildings with vertical geometric irregularity and located in Seismic Zones III, IV and V, the earthquake effects shall be estimated by Dynamic Analysis Method.

The geometric non-linearity of high-rise structure can be included in the analysis by considering the P-delta effect acting in the structure. P-delta effect can be classified into two, one is considering the effect at each floor levels and the next is considering the effect for the whole structure. The P-delta effect at each floor level will not cause a significant change in the response of the structure, but the P-delta effect of the whole structure plays a major role in the response of the structure.

IS Codes does not give any specific guidelines about the P-delta effect, hence the American code is followed to include the P-delta effects in the structure. As per ASCE code, all the structures need not to be analyzed for geometric non-linearity. If the stability coefficient value of the structure calculated as per the guidelines given in the code is less than the limiting value, then P-delta effects need not to be considered, if the value of the stability coefficient exceeds the limiting value, then P-delta effects must be considered during the analysis. If the stability coefficient value exceeds the maximum specified value, then the P-delta effects are very high and the structure need to be redesigned by changing the orientation of the structure.

2. Building and Material Configuration

A G+50 Commercial RC Structure of moment resisting frames with core type shear wall is considered for the analysis. The specification and the size of the beams are 300 x 500 mm, columns are 600 x 600 mm, slab is 150 mm, core wall is 250 mm. The materials considered are concrete of grade M50 and rebar of yield strength Fe 500.

The plan of the considered G+50 commercial RC structure is with eight bays of 5m each along X axis and five bays of 5m each along Y axis as shown in fig. 1. The project information is shown in Table 1.

Table 1Project Information

Project Information				
1	Plan Area	40 X 25	sq.m	
2	No. of Stories	G+50		
3	Floor to floor Height	3	m	
4	Depth of Foundation	2	m	From GL
5	Elevation	153	m	From GL
6	Total Height of Building	155	m	
7	Location	Chennai		

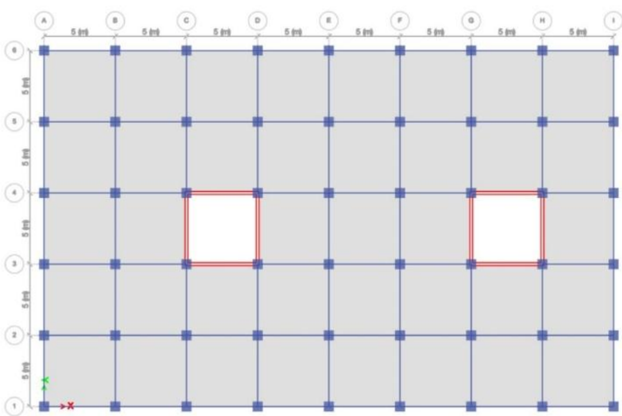

Figure 1 Plan of the Structure

The elevation of the RC structure with floor-to-floor height is 3m. The top of the footing below the ground level is 2m. The elevation of the building from the ground level is 153m and the total height of the building is 155m.The 3D view of the considered G+50 commercial

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RC structure is with floor plan 40m x 25m upto 40th storey. The floor plan is reduced to 25m x 25m beyond 40th storey. As per IS 1893:2016 the considered structure is a irregular structure which comes under vertical irregularity as per IS 1893-2016. The three-dimensional view of the structure is shown in fig 2.

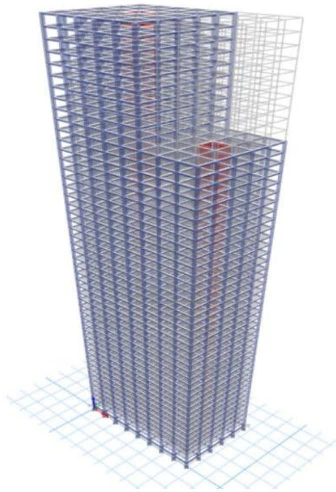

Figure 2 3D View of the Structure

3. Load Data

The dead load and live load considered for the analysis of the structure are referred from IS 875 Part 1 and Part 2. The dead load details are tabulated in Table 2.The thickness of the slab is taken as 150 mm throughout the entire building. The super imposed load for slab is taken as 1.5 kN/sq.m and for roof it is taken as 2 kN/sq.m. The thickness of the brick wall is taken as 230mm both for exterior and interior segments with unit weight of 18.85 kN/cu.m. The plastering for wall is also considered for 20mm on each side with unit weight as 20.40 kN/cu.m. The parapet wall is considered for a height of 1m along with the plaster.

The live load is taken as 4 kN/sq.m since it is a commercial building. Since access is provided, the roof live load is taken as 1.5 kN/sq.m. and as per the code guidance the staircase live load is taken as 4 kN/sq.m. The live load details are tabulated in Table 3.

Table 2 Dead Load

Dead Load				
1	Selfweight	1.0	Factor	Beam,Column, Slab
2	SIDL for Floor Finish	1.5	kN/sq.m	
3	SIDL for Roof Finish	2	kN/sq.m	
4	Wall Load	18.85	kN/cu.m	IS 875 Part I
5	Wall Thickness	0.23	m	9" Bricks
6	Height of Wall	2.7	m	
7	Height of Parapet Wall	1	m	
8	Mortar	20.40	kN/cu.m	IS 875 Part I
9	Thickness of Plaster	20	mm	on each side
10	Height of Plaster	3	m	
11	Wall Load	11.71	kN/m	
12	Plaster	2.448	kN/m	

13	Total Wall Load	14.15	kN/m	
14	Parapet Wall Load	5.66	kN/m	

Table 3Live Load

Live Load				
1	Floor Slab (Commercial)	4	kN/sq.m	IS 875 Part II
2	Staircase Slab	4	kN/sq.m	IS 875 Part II
3	Roof Slab	1.5	kN/sq.m	IS 875 Part II

4. Seismic Load Data

The seismic load data details are given in Table 4. The structure is analysed for seismic zones III, IV, V. The type of soil is assumed as medium soil. The structure is considered as a Special Moment Resisting Framed structure as per IS13920-2016. The approximate natural period of the structure in both axes are calculated as per IS 1893:2016.

Table 4 Seismic Load Data

Earthquake Load Data			
1	Zone Location	Zone III	
		Zone IV	
		Zone V	
2	Zone Factor for Zone III	0.16	IS 1893-2016
	Zone Factor for Zone IV	0.24	IS 1893-2016
	Zone Factor for Zone V	0.36	IS 1893-2016
3	Soil Type (Assumed)	II	Medium
4	Importance Factor	1.2	IS 1893-2016
5	Response Reduction Factor-SMRF	5	IS 1893-2016
6	Approx. Natural Period Tx	2.205	sec
7	Approx. Natural Period Ty	2.790	sec
8	Type of Analysis	Linear Dynamic Analysis (RS)	
		Non-Linear Static (P-Delta)	

5. Load Combination

The lateral load analysis is carried out for different load combinations as specified in 1893:2016. The load combinations are given separately for both orthogonal structure and non-orthogonal structure. The guidelines for non-orthogonal structure are considered for the analysis. The following load combinations are used for analysis.

Limit state of collapse combination

1 1.5 (DL+LL)
2 1.2 (DL + IL + ELX + 0.3ELY)
3 1.2 (DL + IL + ELX - 0.3ELY)
4 1.2 (DL + IL - ELX + 0.3ELY)
5 1.2 (DL + IL - ELX - 0.3ELY)

6 1.2 (DL + IL + ELY + 0.3ELX)
7 1.2 (DL + IL + ELY - 0.3ELX)
8 1.2 (DL + IL - ELY + 0.3ELX)
9 1.2 (DL + IL - ELY - 0.3ELX)
10 1.5 (DL + ELX + 0.3ELY)
11 1.5 (DL + ELX - 0.3ELY)
12 1.5 (DL - ELX + 0.3ELY)
13 1.5 (DL - ELX - 0.3ELY)
14 1.5 (DL + ELY + 0.3ELX)
15 1.5 (DL + ELY - 0.3ELX)
16 1.5 (DL - ELY + 0.3ELX)
17 1.5 (DL - ELY - 0.3ELX)

Limit state of Service combination

1 0.9 DL + 1.5 (ELX + 0.3ELY)
2 0.9 DL + 1.5 (ELX - 0.3ELY)
3 0.9 DL - 1.5 (ELX + 0.3ELY)
4 0.9 DL - 1.5 (ELX - 0.3ELY)
5 0.9 DL + 1.5 (ELY + 0.3ELX)
6 0.9 DL + 1.5 (ELY - 0.3ELX)
7 0.9 DL - 1.5 (ELY + 0.3ELX)
8 0.9 DL - 1.5 (ELY - 0.3ELX)
9 1.2 (DL + IL + RSX + 0.3RSY)
10 1.2 (DL + IL + RSY + 0.3RSX)
11 1.5 (DL + RSX + 0.3RSY)
12 1.5 (DL + RSY + 0.3RSX)
13 0.9 DL + 1.5 (RSX + 0.3RSY)
14 0.9 DL + 1.5 (RSY + 0.3RSX)

6. P-Delta Consideration

As per ASCE code, the stability coefficient ‘ϴ’ of the structure should be calculated for the P-Delta analysis. For P-Delta analysis, the total vertical design load of the structure, the design storey drift, the importance factor, the seismic shear force acting at each level, the storey height below the level and the deflection amplification factor are required, which can be calculated from the pre-analysis of the structure.

After calculating the stability coefficient ‘ϴ’ of the structure, the limiting value of stability coefficient ‘Θ_{limit}’ is calculated as per the guidelines of ASCE. For calculating stability coefficient, the ratio between shear demand and shear capacity of the structure is required, and is calculated from the pre-analysis results. In no case the value of stability coefficient ‘ϴ’ and limiting value of stability coefficient ‘Θ_{limit}’ should exceed ‘Θ_{max}’ the value being 0.25 as per ASCE.

Based on the values of stability coefficient ‘ϴ’ and limiting value of stability coefficient ‘Θ_{limit}’ the structure can be classified into three categories. Category I is P-Delta consideration is not required, Category II is P Delta consideration is required and Category III is the structure needs to be redesigned. If ‘ϴ’ < ‘Θ_{limit}’ < ‘Θ_{max}’ then the structure falls under Category I. If ‘Θ_{limit}’ < ‘ϴ’ < ‘Θ_{max}’ then the structure falls under Category II. If ‘ϴ’ > ‘Θ_{max}’ then the structure falls under Category III.

After pre-analysing the structure, with the obtained values of total vertical design load of the structure, the design storey drift, the importance factor, the seismic shear force acting at each level, the storey height below the level and the deflection amplification factor, the stability coefficient of the considered structure is calculated. The maximum obtained value of the Stability coefficient 'ϴ' is 0.2345 which is less than the maximum value Θ_{max} = 0.25. Hence the structure falls under either category I or category II. Therefore, the structure need not be redesigned.

To find whether the structure falls under category I or Category II the limiting value of the stability coefficient 'Θ_{limit}' need to be calculated as per ASCE and the value is 0.1. Here, the pre-analysis results shows that for the structure, 'Θ_{limit}' < 'ϴ' < 'Θ_{max}' which clearly implies that the structure falls under the category II which means the second order moment in the structure is noticeable and those second order moment must be added to the first order moment and has to be analysed accordingly. Also, those final moments are to be considered for designing the structure. In this case the second order moment is noticeable and cannot be neglected but the second order moments are not very high.

7. Results

The considered structure of G+50 storeys is analysed using ETABS software by both Linear dynamic method (Response spectrum method) as per IS 1893-2016 and Non-linear static method (P Delta analysis) as per ASCE 07. The output such as storey displacement, storey drift and storey shear at each level are taken and the results are compared between these two analysing methods for seismic zones III, IV and V. The significance of P delta analysis is studied for seismic zones III, IV and V using ETABS software.

The storey displacement is obtained at each level by both linear dynamic method (Response spectrum method) and non-linear static method (P Delta analysis). The graphical representation of the storey displacement at each level obtained by Linear dynamic method in Seismic zones III, IV, V is shown in fig 3.

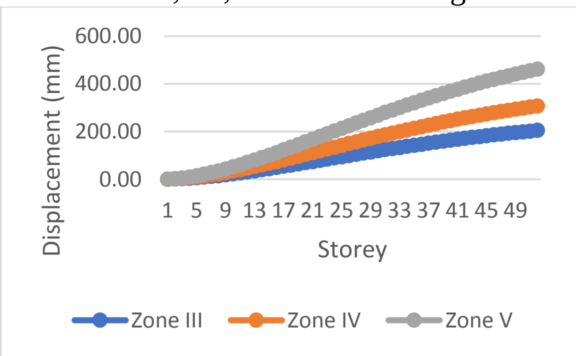

Figure 3 Storey displacements by Linear Dynamic Method

The graphical representation of the storey displacement at each level obtained by non-linear static method (P Delta analysis) in Seismic zones III, IV, V is shown in fig 4.

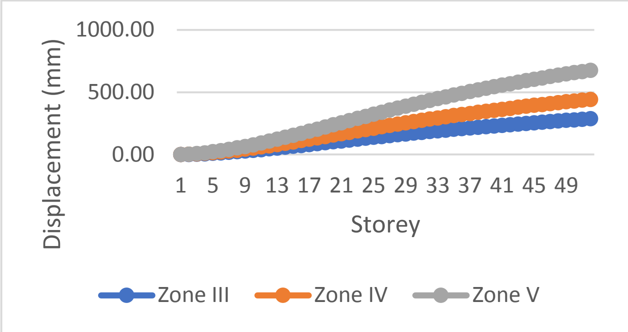

Figure 4 Storey Displacement by P Delta Analysis

The storey drift is obtained at each level by both Linear dynamic method (Response spectrum method) and Non-linear static method (P Delta analysis). The graphical representation of the storey drift at each level obtained by Linear dynamic method in Seismic zones III, IV, V is shown in fig 5.

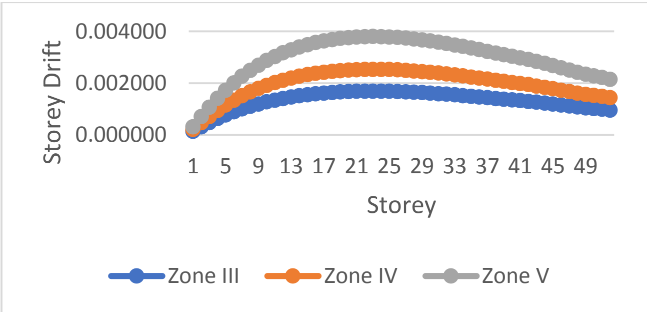

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Figure 5 Storey Drift by Linear Dynamic Method

The graphical representation of the storey drift at each level obtained by Non-linear static method (P Delta analysis) in Seismic zones III, IV, V is shown in fig 6.

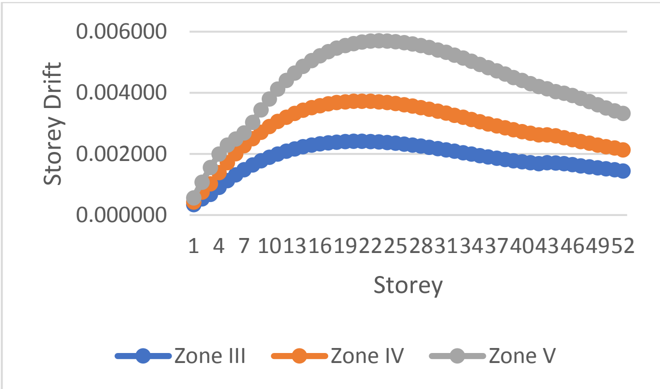

Figure 6 Storey Drift by P Delta Analysis

The graphical representation of the storey shear at each level obtained by Linear dynamic method in Seismic zones III, IV, V is shown in fig 7.

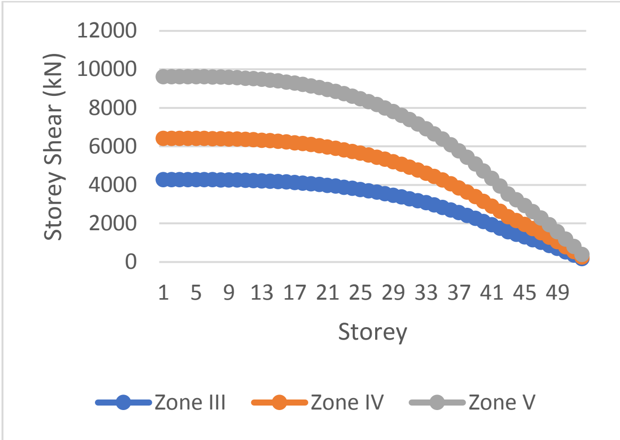

Figure 7 Storey Shear by Linear Dynamic Method

The graphical representation of the storey shear at each level obtained by Non-linear static method (P Delta analysis) in Seismic zones III, IV, V is shown in fig 8

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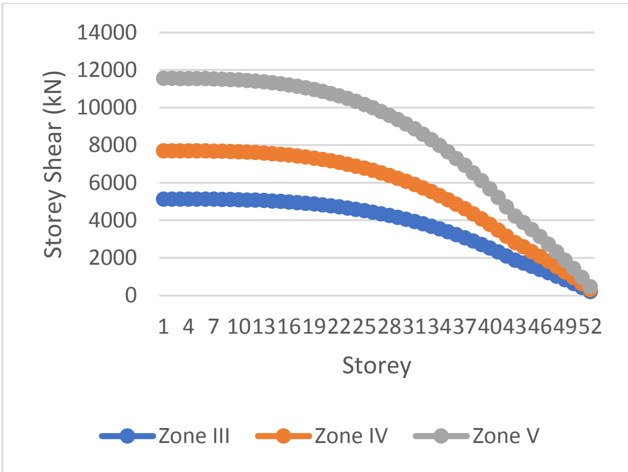

Figure 8. Storey Shear by P Delta Analysis

8. Comparison of Results

The storey displacement comparison at each level in seismic zones III, IV, V is done by Linear dynamic method (Response spectrum method) and Non-linear static method (P Delta analysis) are shown in fig 9, fig 10 and fig 11 respectively.

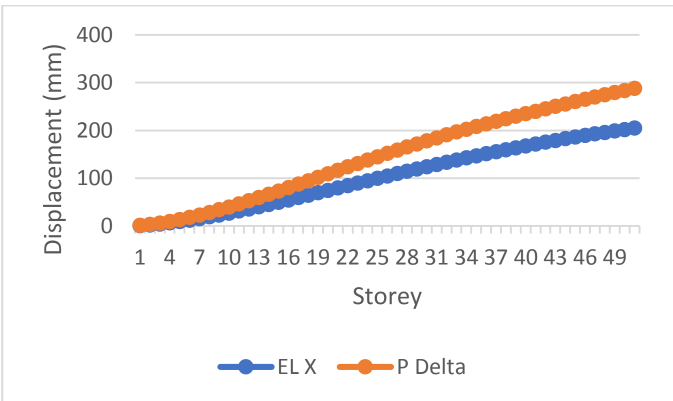

Figure9 Displacement (mm) Comparison in Zone III

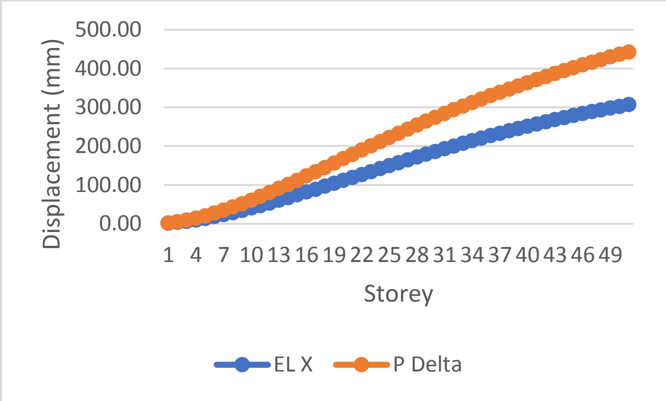

Figure 10 Displacement (mm) Comparison in Zone IV

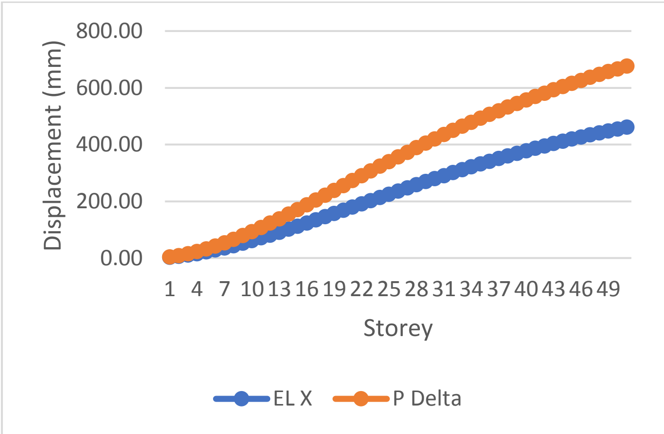

Figure 11 Displacement (mm) Comparison in Zone V

The storey drift comparison at each level in seismic zones III, IV, V is done by Linear dynamic method (Response spectrum method) and Non-linear static method (P-Delta analysis) are shown in fig 12, fig 13 and fig 14 respectively.

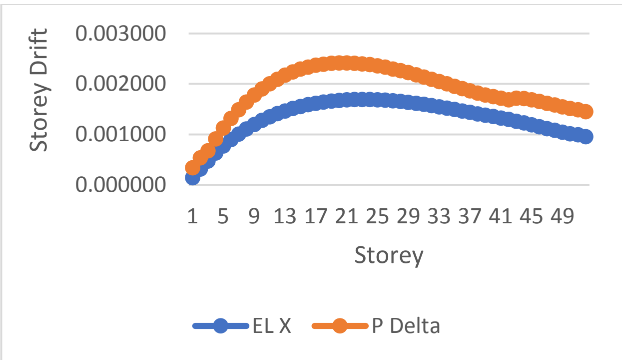

Figure12 Storey Drift Comparison in Zone III

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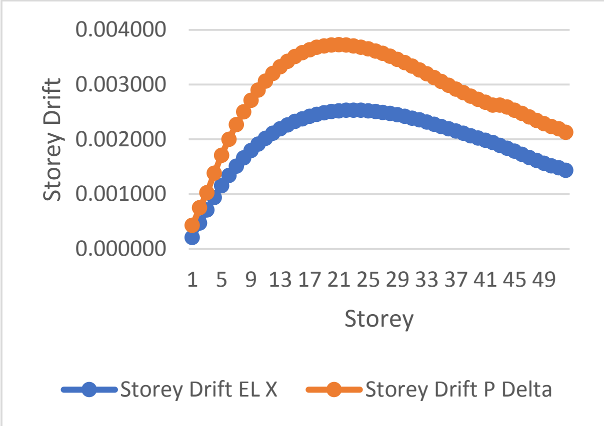

Figure13 Storey Drift Comparison in Zone IV

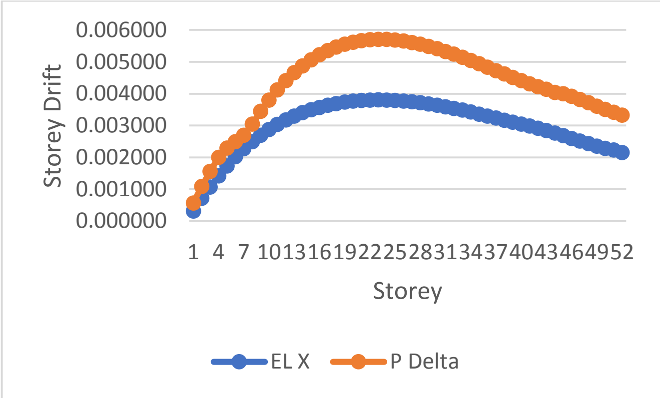

Figure14 Storey Drift Comparison in Zone V

The storey shear comparison at each level in seismic zones III, IV, V is done by Linear dynamic method (Response spectrum method) and Non-linear static method (P Delta analysis) are shown in fig 15, fig 16 and fig 17 respectively.

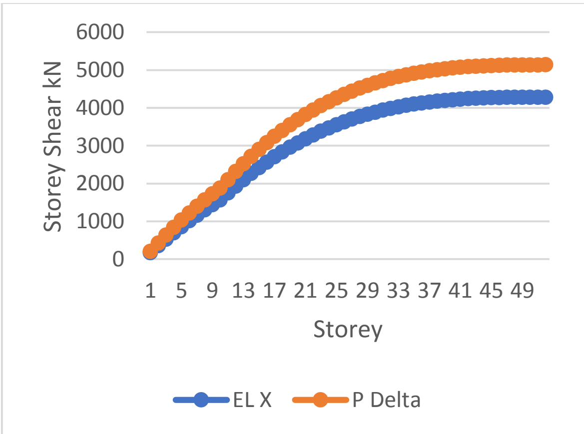

Figure 15 Storey Shear (kN) Comparison in Zone III

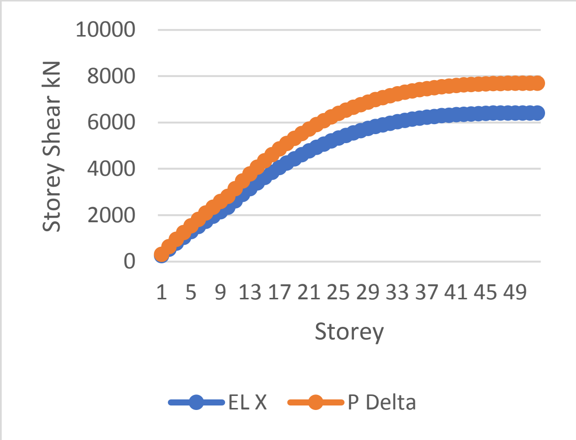

Figure 16 Storey Shear (kN) Comparison in Zone IV

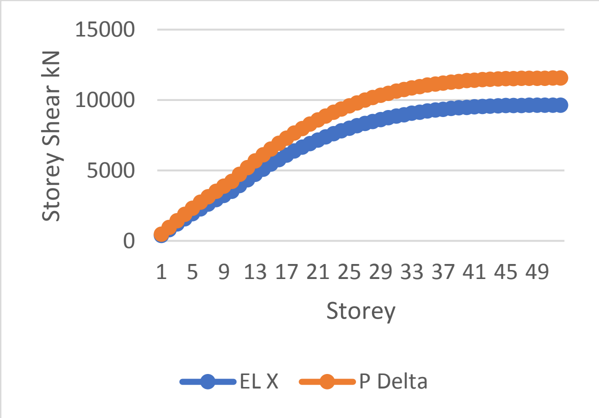

Figure 17 Storey Shear (kN) Comparison in Zone V

9. Conclusion

The peak value of displacement at zone III obtained by Linear dynamic method is 204.82 mm and by P- Delta method is 287.92 mm which is **41% more** than that of linear dynamic analysis. The peak value of displacement at zone IV obtained by Linear dynamic method is 307.23 mm and by P-Delta method is 443.19 mm which is **44% more** than that of linear dynamic analysis. The peak value of displacement at zone V obtained by Linear dynamic method is 460.85 mm and by P-Delta method is 287.92 mm which is **41% more** than that of linear dynamic analysis. Fig 18 shows the peak displacement values in all the three zones using both the methods.

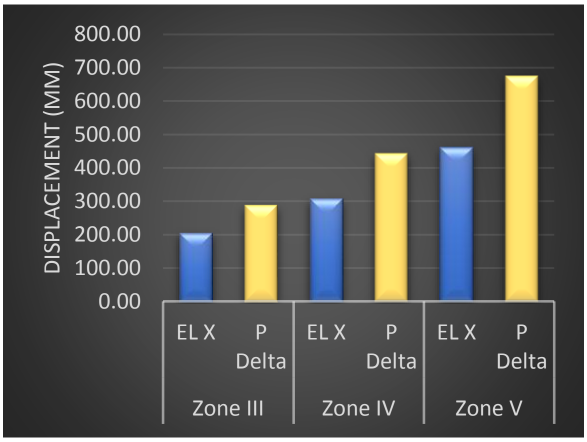

Figure 18 Peak Displacement (mm) Comparison

The peak value of the storey drift at zone III obtained by Linear dynamic method is 0.00169 and by P-Delta method is 0.0024 which is **43% more** than that of linear dynamic analysis. The peak value of the storey drift at zone IV obtained by Linear dynamic method is 0.0025 and by P-Delta method is 0.0037 which is **47% more** than that of linear dynamic analysis. The peak value of the storey drift at zone V obtained by Linear dynamic method is 0.0038 and by P-Delta method is 0.0057 which is **50% more** than that of linear dynamic analysis. Fig 19 shows the peak storey drift values in all the three zones using both the methods.

In addition to that in Zone V by P-delta analysis the value of the peak storey drift exceeds the maximum value specified in IS 1893-2016 which is 0.004 but the value obtained using linear dynamic method is less than the limiting value as specified in the code.

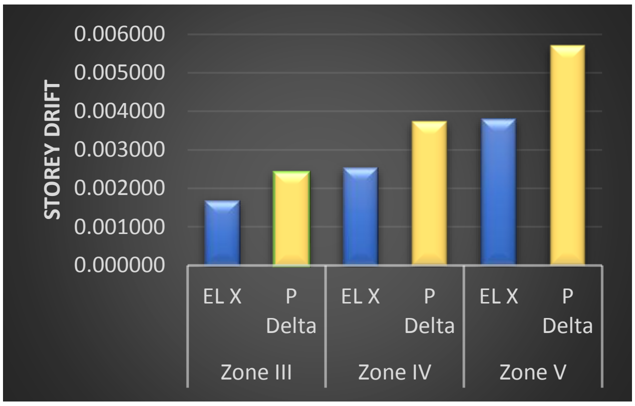

Figure19 Peak Storey Drift Comparison

The peak value of the storey shear at zone III obtained by Linear dynamic method is 4281 kN and by P-Delta method is 5137 kN which is **20% more** than that of linear dynamic analysis. The peak value of the storey shear at zone IV obtained by Linear dynamic method is 6421 kN and by P Delta method is 7705 kN which is **20% more** than that of linear dynamic analysis. The peak value of the storey shear at zone V obtained by Linear dynamic method is 9632 kN and by P-Delta method is 11558 kN which is **20% more** than that of linear dynamic analysis. Fig 20 shows the peak storey shear values in all the three zones using both the methods.

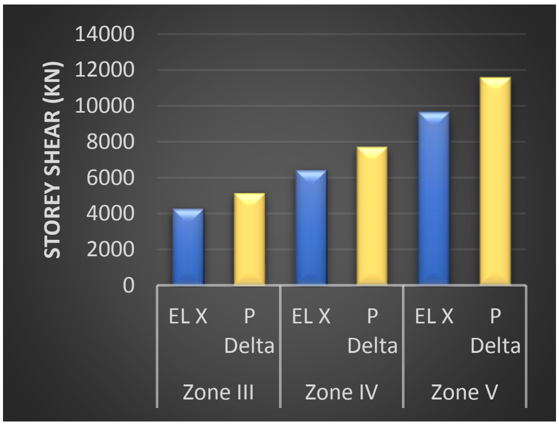

Figure 20 Peak Storey Shear Comparison

From the above comparison of results between the analysis methods, it is clear that if is found that the P-delta effect is significant in a structure as per ASCE code, even though it is analysed by IS methods considering geometric irregularity, non-linear static analysis has to be performed so that the structure can be made more sustainable under seismic actions irrespective of the seismic zones.

10.Acknowledgement

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